S-415-201

GOES ADVANCED BASELINE IMAGER (ABI)

PERFORMANCE AND
OPERATION REQUIREMENTS

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1.0 SCOPE

1.1 IDENTIFICATION

This Sensor Performance and Operations Requirements sets forth the performance requirements for the NOAA Advanced Baseline Imager (ABI).

1.2 MISSION OVERVIEW

The ABI objectives are as follows:

a) Provide environmental data that will be used by NOAA and other public and private agencies to produce routine meteorological analyses and forecasts
b) Maintain continuity of GOES services to the user agencies
c) Provide environmental data that can be used to expand knowledge of mesoscale and synoptic scale storm development and provide data that may be used to help in forecasting severe weather events
d) Provide data that may be used to extend knowledge and understanding of the atmosphere and its processes (e.g., by viewing the evolution and motion of storms and other atmospheric phenomena) in order to improve short/long-term weather forecasts

The ABI instrument, designated as ABI in this document, provides data to the ABI Ground System, designated as ABI-GS in this document, via the spacecraft communication system. The ABI-GS takes the ABI data, spacecraft telemetry data, orbit determination data and other required information and autonomously generates radiometrically calibrated and navigated data for the NOAA users. The ABI-GS will be procured by the government but may implement algorithms developed by the vendor to satisfy ABI performance requirements. This specification only applies to the ABI Instrument but the ABI contractor must have an understanding of the total system (see section 2, reference documents) to assure that the ABI-GS will be able to provide the required data.

Preliminary government studies indicate that the ABI-GS will calibrate then resample the ABI data to generate the fixed grid output on parallel North-South lines with the pixels on the specified output fixed grid. Resampling requires that the raw imagery be adequately sampled to maintain radiometric accuracy after resampling. The specified ABI performance parameters such as MTF, band to band coregistration, step and settle response, etc. will be measured after the resampler.

1.3 DOCUMENT OVERVIEW

This document contains all performance requirements for the sensor except those labeled “(TBD)”, “(TBS)”, and “(TBR)”. The term “(TBD)” applied to a missing requirement means that the contractor <u>should</u> determine the missing requirement in coordination with the government. The term "(TBS)" means that the government will supply the missing information in the course of the contract. The term "(TBR)" means that the requirement is subject to review for appropriateness by the contractor or the government. The government may change "(TBR)" requirements in the course of the contract.

1.3.1 CONFLICTS

In the event of conflict between the referenced documents and the contents of this specification, the contents of this specification **shall** be the superseding requirements.

In the event of a conflict involving the external interface requirements, or in the event of any other unresolved conflict, the NASA contracting officer **shall** determine the order of precedence.

1.3.2 REQUIREMENT WEIGHTING FACTORS

The requirements stated in this specification are not of equal importance or weight. The following three paragraphs define the weighting factors incorporated in this specification.

- **Shall** designates the most important weighting level; that is, <u>mandatory</u>. Any deviations from these contractually imposed mandatory requirements require the approval of the contracting officer.
- <u>Should</u> designates an intermediate weighting that indicates the requirements requested by the government are not mandatory. These are goal requirements that would greatly enhance the utility of the data if they were met. Unless required by other contract provisions, noncompliance with the <u>should</u> requirements does not require approval of the contracting officer, but shall require documented technical substantiation
- *Will* designates the lowest weighting level. These *will* requirements designate the intent of the government and are often stated as examples of acceptable designs, items, and practices. Unless required by other contract provisions, noncompliance with the *will* requirements does not require approval of the contracting officer and does not require documented technical substantiation.

1.3.3 DETECTOR AND PIXEL DEFINITION

Throughout this document, the term 'detector sample' refers to a physical detector and its output after the A/D converter. The term 'pixel' applies to data samples after resampling and ground processing.

1.3.4 REQUIREMENTS APPLICABILITY

All requirements **shall** apply over the entire life (3.2.11) of the ABI. All ABI requirements will be in metric units except large angles may be in degrees.

2.0 APPLICABLE DOCUMENTS

The following documents provide background and context for this ABI RFP specification. These documents are not available at this time. They will be available in the future from the GOES ABI project library at NASA/GSFC by contacting the GSFC GOES Program Office at (301)-286-1384.

2.1 ABI PROJECT DOCUMENTS

Organization / Date	Title
NOAA/NESDIS / November, 1999	ABI Phase A report
NASA/GSFC / TBS	ABI Statement of Work (SOW)
NASA/GSFC / TBS	ABI to spacecraft IRD
NASA/GSFC / TBS	ABI Pre-launch testing requirements

2.2 REFERENCE DOCUMENTS (TBR)

The following documents are for reference only and do not form a part of this specification. They are listed here because various parts of the specification refer to them.

Document	Title
NOAA NWS ORD for ABI	Operational Requirements Document (ORD) for GOES ABI
NOAA NESDIS TRD for ABI	Technical Requirements Document (TRD) for GOES ABI
H.R.Wu, Proceedings of the 1996 International Conference on Communication Technology, vol. 2, May 5-7, 1996, Beijing, China, pp. 658-661.	A New Distortion Measure for Video Coding Blocking Artifacts"
NIST Special Publication 814 1998 Edition	Interpretation of the SI for the United States and Federal Government Metric Conversion Policy
NOAA DRL 504-11, March 1998	GOES Earth Location Users Guide
FED-STD-209E	Airborne Particulate Cleanliness in Cleanrooms and Clean Zones

Document	Title
ASTME-595-93 (current version)	Standard Test method for Total Mass Loss and Collected Volatile Condensable Materials for Outgassing in a Vacuum Environment
MIL-STD-461 Notice 1	Electromagnetic Emission and Susceptibility Requirements for Control of Electromagnetic Interference
MIL-STD-462 Notice 1	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-1541	Electromagnetic Compatibility Requirements for Space Systems
MIL-B-5087	Bonding, Electrical, and Lighting Protection for Aerospace Systems
NASA RP 1124 Rev 4	Outgassing Data for Selecting Spacecraft Materials, June 01 1997
NASA Publication NHB 5300.4 (3L)	Requirements for Electrostatic Discharge Control, August 1993
GSFC X-900-97-004	Charged Radiation Exposure of Geostationary Orbits for the GOES N,O,P,Q Satellite program
NOAA S24.801 Nov 72	Preparation of Operations and Maintenance Manuals, Revised Apr 97
NOAA S24.806 Jan 86	Software Development, Maintenance, and User Documentation, Revised Apr 94
NOAA S24.809 Dec 89	Grounding Standards
GSFC PPL-21 March 1995	Preferred Parts List, Goddard Space Flight Center (Updated May 1996)
NASA SP-R-0 022A (JSC) 9 Sep 74	General Specification, Vacuum Stability Requirements of Polymeric Material for Spacecraft Application

2.3 STANDARDS (TBR)

Document	Title
CCSDS 203.0-B-1 current version	CCSDS Recommendations for Space Data System Standards. Telecommand, Part 3: Data Management Service, Architectural Definition, Issue 1
CCSDS 701.0-B-2 current version	CCSDS Recommendations for Advanced Orbiting Systems, Networks and Data Links, Architectural Specification

Document	Title
ISO/TC 209 (ISO/DIS 14644-1) Jan 97	Cleanrooms and Associated Controlled Environments
National Aerospace Standard (NAS) 411 Rev 2, 29 Apr 1994	Hazardous Materials Management Program

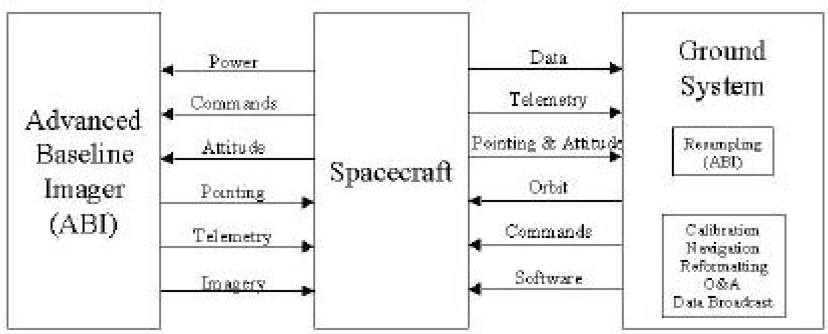
3.0 SENSOR REQUIREMENTS

3.1 DEFINITION

3.1.1 ABI OVERVIEW AND DESCRIPTION

The ABI is a multi-channel, visible through infrared, passive imaging radiometer used to measure environmental data as part of a 3-axis stabilized, geostationary weather satellite system. The ABI, in conjunction with a sounding instrument, remotely collects data on the Earth's surface (land and water) and atmosphere to aid in the prediction of weather and climate monitoring. The ABI data provide moderate spatial and spectral resolution at high temporal and radiometric resolution to accurately monitor rapidly changing weather. Figure 2 shows the notional interfaces among the ABI, spacecraft and ground system.

Figure 1. Notional Interfaces



The requirements in this document pertain to the ABI 'system', which may include scanner, optics, detectors, signal processing electronics and software, and ground processing. The ABI vendor is not responsible for the whole ABI-GS, but certain specifications may require some level of ground processing after collection but before data distribution, i.e. decompression, re-sampling, and calibration. All requirements in this document apply to data after any ground processing except INR requirements in 3.2.4, minus co-registration (3.2.4.5).

3.1.2 TOP LEVEL FUNCTIONS

The ABI system **shall** perform the following functions:

- scene radiance measurement
- radiometric calibration
- star sensing
- on-orbit monitoring of calibration sources and instrument response changes
- acquisition of sensor health and status data

- generation of data streams containing scene radiance, calibration, monitoring, health and status data
- reception and execution of command and control data

3.1.3 ABI Modes

Under all powered modes, the ABI **shall** protect itself from solar damage for a minimum of TBD minutes. Either loss of spacecraft attitude knowledge, a bad ABI pointing command or failure of the ABI or its pointing system could potentially cause ABI to scan through or point at the Sun for an extended period of time. The ABI **shall** implement the following modes as a minimum:

3.1.3.1 Launch Mode

The launch mode is the period of time between lift off and the spacecraft power positive and is anticipated to be less than 2 hours long. The ABI **should** be off, with no power applied for survival heaters or the instrument. During orbit raising, the period of time between power positive and on station operations, the ABI will be in Sensor Off Mode or Safe Hold Mode.

3.1.3.2 Sensor Off Mode

In the Sensor Off mode, no power is supplied to the Sensor except survival heaters will be powered if required. Up to TBD watts of power could be available to the ABI to power a system to protect the instrument from the Sun.

3.1.3.3 Operational Mode

The sensor **shall** be in full functional configuration during this mode. Mission and housekeeping data **shall** be collected. Calibrations and star sensing **shall** be performed during regular operations.

3.1.3.4 Sensor Diagnostic Mode

Diagnostic mode (TBD) **shall** include trouble shooting and uploading of new software.

3.1.3.5 Sensor Safe Hold Mode

The ABI **shall** enter Safe Hold Mode upon command. The ABI <u>should</u> enter Safe Hold Mode autonomously when necessary. In the Safe Hold mode, health and status data are collected and transmitted. Mission and calibration data are not collected. In Safe Hold mode, most components are turned off, with survival heaters activated.

3.1.3.5.1
The Safe Hold Mode is a power conservation mode and the ABI **shall** consume no more than TBD watts. The Sensor **shall** accept a command to go into safe hold mode in the

event the spacecraft enters an anomalous configuration or orientation as determined by the spacecraft computer or the ground system. The return to the Normal Operations Mode requires ground intervention.

3.1.3.5.2
All autonomous operations **shall** be capable of being over ridden by ground command.

3.1.3.5.3
The ABI **shall** be able to accept direct solar illumination through the aperture for TBD minutes without damage.

3.1.3.5.4
The ABI **shall** be able to accept solar illumination at angles between 65° and 90° (TBR) from normal to the radiative cooler for 16 (TBR) minutes without permanent damage. Recovery time to full performance <u>should</u> be less than TBD hours and **shall** be less than 48 hours.

3.1.4 OPERATIONAL AND ORGANIZATIONAL CONCEPT

3.1.4.1 Launch Operations concept

3.1.4.1.1 Pre Launch

The satellite, including the ABI, will be transported to the launch base where final vehicle preparations and checkout will be accomplished. Final pre-launch system verification tests will be accomplished at the launch site.

3.1.4.1.2 Launch and Injection

During launch the ABI <u>should</u> be turned off in order to provide protection from the launch environment or to comply with other specified requirements.
During orbit raising and after insertion into its operational orbit, appropriate deployments would be initiated by command. Spacecraft telemetry transmission to ground monitoring stations would be used to the extent practicable during the injection phase.

3.1.4.2 On-orbit Operations

The ABI **shall** fly aboard a 3-axis stabilized, geostationary spacecraft with orbital limits constraints in the ABI IRD. Regular operations **shall** consist of acquiring data from selectable image areas (e.g., CONUS, full Earth disk), non-routine imaging of selectable variable size areas, space view and blackbody viewing for calibrations, and star sensing (ref 3.2.2.5). The ABI **shall** be capable of starting the acquisition of a new image, after a commanded reset and image coordinate upload, within 30 (TBR) seconds.

3.1.4.3 Zones of Reduced Data Quality

3.1.4.3.1 Operational zone

The ABI **shall** meet all of its operational requirements for all pixels greater than 10° (TBR) from the center of the Sun. The ABI should meet all of its operational requirements for all pixels greater than 5° (TBR) from the center of the Sun. See Figures 3 and 4 for a pictorial description for both 3.1.4.3.1 and 3.1.4.3.2. Beyond the outer circle around the sun all requirements **shall** be met. Between the two circles around the sun, the reduced requirements of 3.1.4.3.2 **shall** be met.

3.1.4.3.2 Restricted zone

The ABI **shall** meet all requirements, except the NEDT in paragraph 3.2.2 and paragraph 3.2.5.1, for all pixels between 3° and 10° from the center of the Sun. The ABI should meet all requirements, except paragraphs 3.2.2 and 3.2.5.1, for all pixels between 2° and 5° from the center of the Sun. In place of the NEDT in 3.2.2 and 3.2.5.1 the ABI **shall** meet the following two requirements:

- NEDT < 2x normal specification (ref. 3.2.2)
- Accuracy of temperature measurements < 2x normal specification (ref. 3.2.5.1)

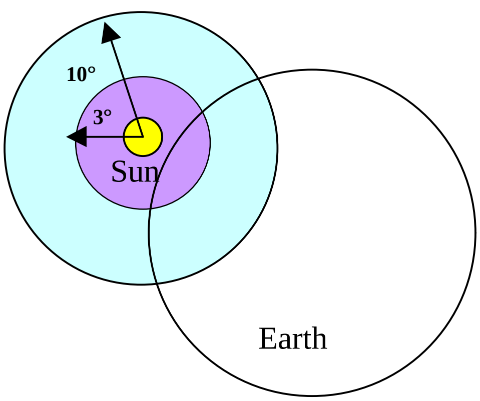


Figure 2. Pictorial of required (**shall**) operational and restricted zones

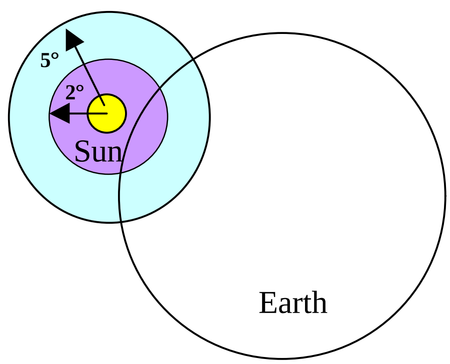


Figure 3. Pictorial of goal (should) operational and restricted zones

3.1.4.4 Scanning Through the Sun

Ground operations will not routinely scan the ABI closer than 1.4 degrees from any detector to the center of the sun. The ABI **shall** be able to scan through the Sun at its normal scan rate without sustaining damage during anomalous conditions.

3.1.4.5 Eclipse

The ABI **shall** be capable of continuous operation through eclipse periods and **shall** meet all requirements.

3.1.4.6 Flexible and Efficient Scan Pattern

The ABI **shall** be designed so as to minimize the complexity of the required commanding to change coverage and minimize the impact of the Sun on data loss. Some examples of possible approaches may include, but are not limited to:

- All references to locations such as Latitude and Longitude will be converted to the ABI scan coordinate reference frame by the ground system.
- Command the Scanning mode, i.e. Full Disk + CONUS, Full Disk + 1000Km frame or other scan patterns to be identified by the proposers.
- Command the location of the corners of CONUS
- Command the location of the corners of the 1,000km frame
- Commands to minimize the impact of the Sun on Data Quality and Quantity
- Split the Full Earth into 3 segments, two are the normal E-W width and one segment has a commanded reduced E-W width specified on the East or West side to minimize the impact of the sun.
- The above command information will be uploaded during earlier operations and activated with a single command.

3.1.4.7 Operations after Maneuvers

3.1.4.7.1 Yaw Flip

Twice per year, within ±4 (TBR) days of the equinoxes, the GOES spacecraft is expected to rotate 180° so that the solar loading on the instrument radiative coolers is reduced. This will occur any time during the 8 (TBR) day window in either axis so that the sun or Earth does not illuminate the cooler during the maneuver. The maneuver is expected to last less than 3 (TBR) hours. The net effect reverses the sign of the roll and pitch axis while maintaining yaw pointing at nadir. The ABI **shall** meet radiometric (3.2.5) and noise (3.2.2) requirements within 1 hour after the yaw flip. The ABI **shall** meet INR requirements (3.2.4) within 1 day after the yaw flip.

3.1.4.7.2 North/South Station Keeping

The ABI **shall** meet all radiometric, coverage and INR requirements within 30 minutes following spacecraft maneuvers. The ABI <u>should</u> meet all radiometric, coverage, and INR requirements within 5 minutes following spacecraft maneuvers.

3.1.4.7.3 Post Storage Activation

The GOES spacecraft and instruments are designed to allow for up to 2 years of on orbit storage. The ABI **shall** meet all requirements within TBS days of instrument turn on after post storage activation.

3.1.4.8 Infrared Detector Operating Temperatures

The desired operation temperature **shall** be programmable by ground command. The operating temperatures **shall** have TBD Kelvin margin.

3.2 SENSOR CHARACTERISITICS

3.2.1 IMAGE CHARACTERISTICS

3.2.1.1 Image Update Rate

The ABI **shall** be capable of acquiring full resolution data from all spectral channels in the following two modes.

Mode 1 -In a 30-minute interval the ABI **shall** acquire

- 2 Full Disks (ref 3.2.1.1.1)
- 6 CONUS images (ref 3.2.1.1.2) two of which may be extracted from the full disk images if the timing is correct
- all of the required space look and IR calibration data needed to meet the radiometric requirements (ref 3.2.5)
- a minimum of 4 (TBR) stars (ref 3.2.2.5).

Mode 2 -In a 30-minute interval the ABI **shall** acquire

- 2 Full Disks (ref 3.2.1.1.1)
- 60 mesoscale images (ref 3.2.1.1.3)
- all of the required space look and IR calibration data needed to meet the radiometric requirements (ref 3.2.5)
- a minimum of 4 (TBR) stars (ref 3.2.2.5).

The ABI <u>should</u> be capable of acquiring full resolution data from all spectral channels in the following mode.

Mode 3 -In a 30-minute interval the ABI <u>should</u> acquire

- 2 Full Disks (ref 3.2.1.1.1)
- 6 CONUS images (ref 3.2.1.1.2) two of which may be extracted from the full disk images if the timing is correct
- up to 60 uniformly spaced mesoscale images (ref 3.2.1.1.3)
- all of the required space look and IR calibration data needed to meet the radiometric requirements (ref 3.2.5)
- a minimum of 4 (TBR) stars (ref 3.2.2.5).

3.2.1.1.1 Full Disk (13,000 km diameter) in less than or equal to 15 minutes, all corresponding pixels in consecutive frames equally spaced in time 15 minutes apart ± 30 seconds.

3.2.1.1.2 CONUS area (defined as a nadir-viewed rectangle 5000x3000 kilometers approximately in the geographic area encompassing 10N-60N latitude and 60W-125W longitude in less than or equal to 5 minutes, all corresponding pixels in consecutive frames equally spaced in time 5 minutes apart ± 30 seconds.

3.2.1.1.3 Mesoscale image (defined as the equivalent of a 1000x1000 kilometer nadir-viewed area viewed anywhere on the disk) in less than or equal to 30 seconds, all corresponding pixels in consecutive frames equally spaced in time 30 seconds apart ± 5 seconds.

3.2.1.2 Field of Regard

The ABI's unvignetted Field of Regard (FOR) **shall** include a circle of at least 20 degrees in diameter with its center at the sub-satellite point. The FOR **shall** be large enough to allow the ABI to view space for instrument background subtraction and to view enough stars to support the star sense requirements of 3.2.2.3.

3.2.1.3 Simultaneity

3.2.1.3.1 Corresponding pixels in all spectral channels **shall** be collected within 5 seconds of each other.
3.2.1.3.2 Adjacent North/South pixels, in resampled output data, **shall** be collected within 30 seconds of each other.
3.2.1.3.3 Adjacent East/West pixels, in resampled output data, **shall** be collected within 15 seconds of each other.

3.2.1.4 Data Timeliness

Data buffering in the ABI <u>should</u> be minimized and **shall** have a maximum delay of 30 (TBR) seconds after the data is sensed by the detectors for a CONUS or mesoscale image and less than 5 (TBR) minutes maximum delay after the data is sensed by the detectors for a Full Disk image.

3.2.1.5 Time Tagging of data

The data **shall** be time identified so that the time any detector sample in the data was acquired can be determined to within 0.001 seconds relative to the spacecraft provided clock information. The spacecraft clock is synchronized to UT to better then 0.1 seconds.

3.2.1.6 Fixed Grid Format

The distributed, calibrated and navigationally corrected image data **shall** be rectified to a fixed grid. The grid is defined relative to the geostationary satellite position centered anywhere on the equator. The data samples **shall** have an angular separation in both the East/West and North/South directions of 14 μrad in the 0.64 micron channel and 56 μrad in all other channels.

3.2.1.7 Data Acquisition Direction

The ABI data acquisition **shall** be independent of yaw flip. The ABI should acquire data in a predominantly East/West and/or West/East direction. Image acquisition should begin with the northern most coordinate and proceed south.

3.2.1.8 Data Collection Overlap

The ABI **shall** overlap data collection such that every pixel in the final image product is generated from raw samples of the same swath or block, not adjacent ones. In addition, the overlap **shall** consider changes in spacecraft attitude of up 250 μrad in any 30-second period. A Dynamic Motion Compensation signal may be available, and is describe in the IRD section 3.2.4.1.

3.2.2 CHANNEL DEFINITIONS, NEDT, DYNAMIC RANGE

3.2.2.1 Baseline

The ABI **shall** collect imagery in the following eight channels listed in Table 1 designated by their center wavelength and spectral bandpass half power points in units of microns. Also listed in Table 1 are the required radiometric sensitivity (NEDT) and dynamic range in temperature and spectral radiance units. The term 100% albedo refers to the reflected solar spectrum at the top of the atmosphere.

Table 1. ABI Baseline Channel Descriptions, Radiometric Sensitivity and Dynamic Range

Wavelength (μm)	NedT @300K (K)	NedT @240K (K)	NEdN, or SNR at 100% albedo (mW/m^2/sr/cm^{-1})	Scene T_{min} (K)	Scene T_{max} (K)	N_{max} (mW/m^2/sr/cm^{-1})
0.64 +/- 0.05	-	-	SNR=300:1 NEDN=0.062	N/A	-	18.5
1.61 +/- 0.03	-	-	SNR=300:1 NEDN=0.067	N/A	-	20.2
3.9 +/- 0.1	0.10	1.4	NEDN=0.004	4	375	10.8
6.15 +/- 0.45	0.10	0.4	NEDN=0.05	4	300	21
7.0 +/- 0.2	0.10	0.37	NEDN=0.09	4	300	37
10.7 +/- 0.5	0.10	0.19	NEDN=0.17	4	330	176
12.0 +/- 0.5	0.10	0.18	NEDN=0.18	4	330	190
13.3 +/- 0.3	0.30	0.48	NEDN=0.53	4	305	150

The NEDT is determined for the instrument viewing a 300K±1K and 240K±0.5K constant blackbody scene and is the one sigma variation about the mean. The SNR for the 0.64 micron and the 1.61 micron channel and the NEDN for all other channels is determined for full sun illumination with 100% albedo and an earth scene temperature of 300 K. The dynamic range is the maximum flux at the maximum scene temperature, T_{max}, divided by the NEDN resulting from viewing the minimum scene temperature, T_{min}.

The ABI should have NEDT (@ 300 K) of 0.05 K in all IR channels with wavelengths greater than 3.0 microns.

3.2.2.2 Potential Additional Channels

Table 2 lists the four potential additional channels. The priority listed by center wavelength in microns: 8.5, 10.35, 0.86, and 1.38. If the 10.35 channel is added, the channels in Table 1 **shall** be changed from 10.7 +/- 0.5 to 11.2 +/-0.4 and 12.0 +/- 0.5 to 12.3 +/- 0.5. The addition of the channels **shall** be considered individually and in any combination of two, three and four channels.

Table 2. ABI Potential Additional Channel Descriptions, Radiometric Sensitivity and Dynamic Range

Wavelength (µm)	NedT @300 K	NedT @240 K	NEdN, or SNR at 100% albedo (mW/m^2/sr/cm^{-1})	Scene T_{min} (K)	Scene T_{max} (K)	N_{max} (mW/m^2/sr/cm^{-1})
0.86 +/- 0.05	-	-	SNR=300:1 NEDN=0.076	N/A	-	22.9
1.38 +/- 0.015	-	-	SNR=150:1 NEDN=0.072	N/A	-	21.54
8.5 +/- 0.2	0.10	0.27	NEDN=0.13	4	330	116
10.35 +/- 0.25	0.10	0.21	NEDN=0.17	4	330	161

3.2.2.3 System Spectral Response

The ABI system spectral response **shall** conform to the envelope in Figure 5 and the values in Table 3. The values T1 and T2 in Figure 4 are determined by adding and subtracting the tolerances listed in Table 3 to the upper and lower 50% response points. The percentages listed in figure 4 are of the nominal bandwidths in Table 3. The brightness temperature error due to spectral response uncertainty when viewing two government supplied atmospheres (dry and moist) and using government supplied radiative transfer code **shall** be less than the radiometric accuracy in 3.2.5.1.

3.2.2.3.1 Spectral Response Wavelengths

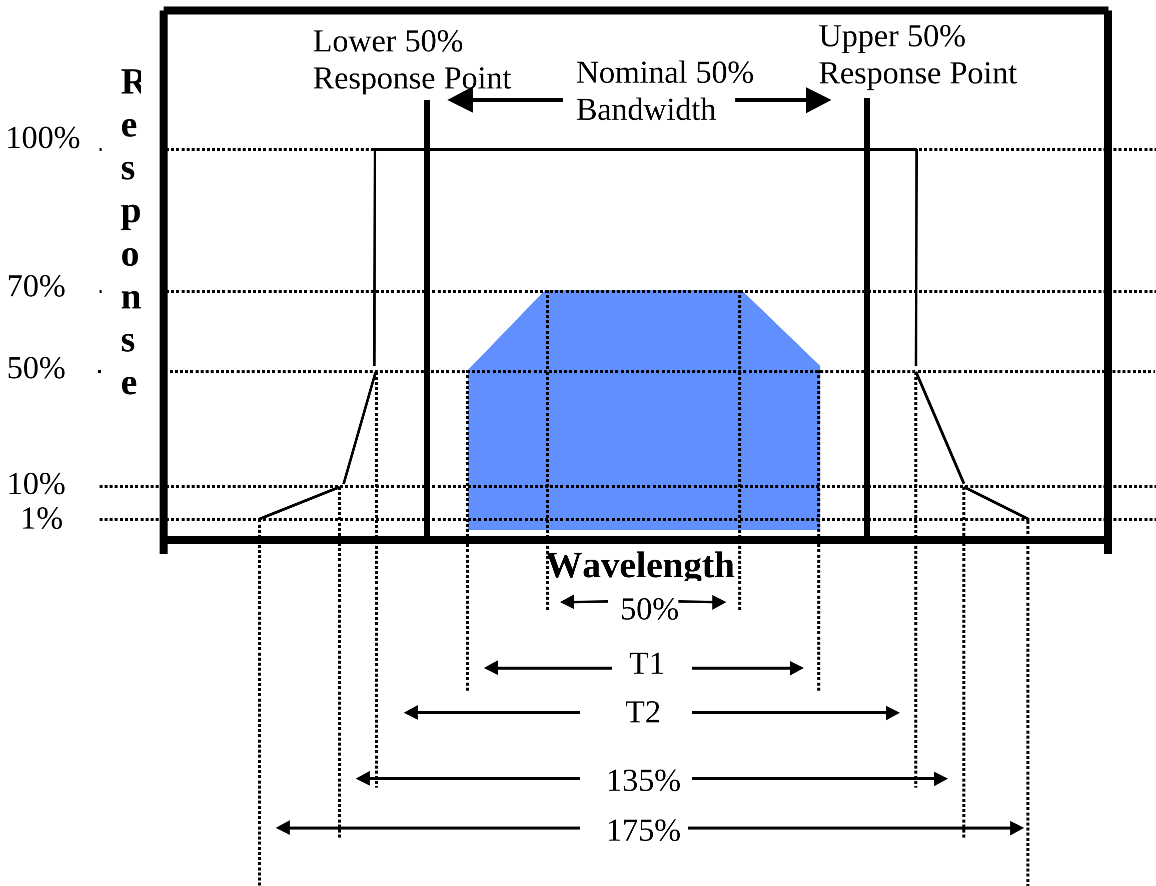


Figure 4. ABI Spectral Response Shape Envelope

Table 3. ABI Spectral Response (TBR) (all value in microns)

Nominal Center Wavelength (μm)	Lower 50% Response Point	Upper 50% Response Point	Nominal 50% Bandwidth
Baseline Channels			
0.64	0.59±0.01	0.69±0.01	0.10
1.61	1.58±0.01	1.64±0.01	0.06
3.9	3.80±0.05	4.00±0.05	0.20
6.15	5.7±0.03	6.60±0.03	0.90
7.0	6.80±0.03	7.20±0.03	0.40
10.7	10.2±0.1	11.2±0.1	1.0
12.0	11.5±0.1	12.5±0.1	1.0
13.3	13.0±0.03	13.6±0.03	0.6
Potential Additional Channels			
0.86	0.81±0.01	0.91±0.01	0.1
1.38	1.365±0.005	1.395±0.005	0.03
8.5	8.3±0.03	8.7±0.03	0.40
10.35	10.1±0.1	10.6±0.1	0.50
11.2	10.8±0.1	11.6±0.1	0.80
12.3	11.8±0.1	12.8±0.1	1.0

3.2.2.3.2 Within Channel Spectral Response Uniformity

All pixels within a channel **shall** have uniform spectral response such that the variation in brightness temperature due to spectral response differences when viewing two, government supplied atmospheres (dry and moist) and using government supplied radiative transfer code, **shall** be less than the NEDN listed in Tables 1 and 2. The variation is defined as one sigma standard deviation about the mean radiance for the channel and atmosphere.

3.2.2.3.3 Out of Band Response

The out of band response is defined in equation 1 as one minus the integrated response between the 1% response points divided by the integrated response from 0.3 (TBR) microns to 20 (TBR) microns. Out of band response **shall** be less than 0.1% of the total signal when viewing either a 300 K blackbody (for channel wavelengths > 3 microns) or a 100% albedo scene above the atmosphere assuming no attenuation.

$$\text{(Equation 1)}\quad 1 - \left(\int_{-l_{1\%}}^{+l_{1\%}} N(l)R(l)\,dl \Big/ \int_{l_{0.3\,mm}}^{l_{20\,mm}} N(l)R(l)\,dl \right) \le 0.001 \quad \text{where}$$

$N(l) = 300$ K blackbody or 100% albedo and

$R(l)$ is the channel relative spectral response

3.2.2.4 Low light visible channel

The ABI <u>should</u> include a low light level (5% albedo TBR) visible (0.64 microns) imaging capability at 50:1 SNR (TBR) and 0.5 km spatial resolution at nadir. One-half kilometer resolution, low-light visible imagery would allow forecasters to discern fog and important thunderstorm outflow boundaries earlier in the morning, as well as later into the evening hours, during severe and tornadic storm events.

3.2.2.5 Star sensing

The ABI **shall** observe stars in at least one Earth imaging visible or near IR channel (or through the same optical train used to collect Earth imaging data using a dedicated star sense array) with an angular instantaneous field of view (IFOV) of no more than 14 µrad. The ABI **shall** acquire data to allow the ABI Ground System to determine the location of any star, using ABI vendor supplied algorithms, of visible magnitude $m_V = 6.0$ or lower (brighter), spectral class B0 or cooler, with respect to the detector's coordinates to within ±10 µrad (3 sigma) (TBR), subject to the constraints below:

3.2.2.5.1 Initial acquisition area

The ABI **shall** be provided with the location of the target star by the spacecraft, in ABI scanner gimbals units, with an error not to exceed ±140 µrad (TBR) in routine operation. The stars move approximately 73 µrad per second relative to nadir and the reference time, near the center of the 30-minute interval for the star locations, will be provided. This information will be provided to the ABI before the start of the 30-minute interval of 3.2.2.5.5.

3.2.2.5.2 Bright object avoidance

The target star **shall** satisfy all of the following conditions:

- The star is > 5.0 degrees (TBR)from the center of the Sun
- The star is > 0.75 degrees (TBR)from the Earth's limb
- The star is > 0.75 degrees (TBR) from the center of the moon
- Any star or planet located < 290 µrad (TBR) from the target star is at least 2 visible magnitudes (TBR) higher (dimmer) than the target star.

3.2.2.5.3 Probability of detection

The probability of detection of a star that satisfies the above conditions **shall** exceed 0.995 (TBR)

3.2.2.5.4 Probability of false alarm

The probability of false alarm, defined as an erroneous detection > 30 μrad (TBR) from the true star location, **shall** not exceed 2e-5 (TBR).

3.2.2.5.5 Timeline

The ABI **shall** be able to detect at least 4 stars in any 30 minute period, assuming that such stars are present within the ABI's field of regard. The ABI **shall** also satisfy all of the requirements of Section 3.2.1.1 Image Update Rate, during this 30-minute period.

3.2.2.5.6 Star location in the field of regard

The Ground System's algorithm for selecting the ABI's stars will attempt to select stars that are well-separated from each other. The ABI **shall** be required to satisfy section 3.2.2.5.5, above, when each star is separated from each other star by > 10 degrees.

3.2.3 SPATIAL RESOLUTION AND SAMPLING

3.2.3.1 System MTF

The ABI spatial resolution is defined by the sensor system modulation transfer function (MTF). The following MTF values are consistent with 0.5 kilometer resolution in the 0.64 micron channel and 2 kilometer resolution in all other channels. The spatial frequencies are measured at nadir. The ABI system MTF, after any ground processing such as resampling or image reconstruction from compressed data and including spacecraft jitter as detailed in the ABI IRD, **shall** meet the requirements listed in Table 4 in both Eeast/West and North/South directions.

Table 4. MTF Requirements for ABI

Visible Channel (0.64 μm)			All other bands		
Spatial Frequency		System MTF	Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)		(km/cyc)	(cyc/rad)	
4.0	9,000	0.90	16.0	2250	0.84
2.0	18,000	0.73	8.0	4500	0.62
1.333	27,000	0.53	5.333	6750	0.39
1.0	36,000	0.32	4.0	9000	0.22

3.2.3.2 Ground Sample Distance

The 0.64 micron channel **shall** have a 0.5 kilometer (TBR, see SOW 2.1.1 study 3) ground sample distance as measured at nadir in both the East/West and North/South dimensions. All other channels **shall** have 1.0 kilometer ground sample distance (TBR, see SOW 2.1.1 study 3) as measured at nadir in both the East/West and North/South dimensions. In both the East/West and North/South dimensions, the calibrated, navigated ground processed data to be distributed to users **shall** have a 0.5 kilometer ground sample distance in the 0.64-micron channel and 2.0 kilometer ground sample distance in all other channels. Resampling requires that the raw imagery be adequately sampled to maintain radiometric accuracy after resampling.

3.2.3.3 Spatial Response Uniformity

The temperature difference between any two channels measured 2 kilometers after an edge from zero radiance to $N_{300\text{ K}}$ (the radiance from a 300 K scene) **shall** agree to within 1 K (TBR).

3.2.4 IMAGE NAVIGATION AND REGISTRATION

Overview

Image navigation refers to the process of assigning latitude and longitude to each image pixel. Image registration refers to the process of maintaining the spatial relationship between pixels within and among images. Errors are measured in angle (μrad), are 3-sigma deviations and refer to all hours of operation unless otherwise specified.

Image navigation and registration results from the combined system performance of the ABI sensor as well as the spacecraft and ground processing subsystems. The contribution of the ABI to navigation and registration errors is primarily due to pointing uncertainties. All navigation and registration requirements listed here refer strictly to the ABI line of sight with respect to its mounting surface due to any non-repeatable causes internal to the instrument.

The ABI Ground System will have information as to the location of the spacecraft, the angular motion (Jitter) of the instrument mounting surface, and the pointing error to nadir.

In order to achieve adequate system navigation and registration, the ABI **shall** be consistent with the following mission system operating conditions:

- Orbital geometry as described in section 3.1.5 of the ABI IRD.

- Predictable pointing errors, such as diurnal orbit errors and thermal distortion as well as sensor misalignment will be corrected for by a predictive scan compensation in the ABI-GS based on landmark observations, sensor star observations and range data. The maximum range of predictive compensation will be ± 8000 μrad (TBR). The spacecraft can make available to the ABI a Spacecraft Motion Compensation (SMC) signal that is an estimate of the attitude of the spacecraft navigation base with respect to nadir.

- During ground processing prior to data distribution, image pixels may be remapped based on landmark observations and measured sensor servo error and spacecraft attitude data (SMC). Sensor servo error and spacecraft attitude data **shall** be included in the ABI data stream. Remapping may include digital filtering, rigid image displacements and rotations, non-rigid image distortions and edge fitting. Remapping **shall** be performed in the ABI-GS in a manner consistent with all other requirements, including system data timeliness and radiometric accuracy.

3.2.4.1 Detector sample navigation

The accuracy of detector sample location knowledge, due to all ABI error sources, within the total field of regard **shall** be less than ±14 μrad (TBR) for local noon ± 8 hours and ±21 μrad for local midnight ± 4 hours. This accuracy **shall** be met for all data acquisition modes, including star sensing. The navigation accuracy <u>should</u> be ±14 μrad for the entire day.

3.2.4.2 Frame to frame registration

Corresponding detector sample locations in two images obtained up to 15 minutes apart **shall** be known to within ±14 μrad (TBR).

3.2.4.3 Within Frame registration

The angular separation between any two detector samples within an image **shall** be known to within ±12 μrad. The angular separation between any two detector samples within an image <u>should</u> be known to within ±7 μrad.

3.2.4.4 Line to line registration

The location of any two neighboring detector samples in adjacent lines, East/West and North/South, **shall** be known to within an accuracy ± 5 μrad.

3.2.4.5 Channel to channel registration after resampling

The ABI should have sufficient stability through launch and over orbital temperature, variations that the following system requirements shall be met with at least a 15% margin. The channel to channel registration after resampling for all channels except the 0.64 micron channel **shall** be less than ±8 μrad. The channel to channel registration after resampling <u>should</u> be less than ±6 μrad. The visible (0.64 micron) channel to all other channels registration after resampling **shall** be less than ±28 μrad. The ABI qualification program shall provide the information as to the relative location of all of the detectors to be used by the ABI Ground System to enable it to resample the data to meet the above requirements. If the inherent stability of the ABI will not meet the above system requirement, algorithms shall be provided to enable determining the necessary relative location of detectors in all bands in orbit using data acquired during normal operation.

3.2.4.6 Diurnal Repeatability of Line of Sight Motion

Line of sight motion refers to the deviation of the Line of Sight of any detector from its ideal direction as defined by the ABI gimbal angles relative to the ABI mounting surface. Line of sight motion occurs due to thermal distortion in the ABI from diurnal solar heating. An ABI design that minimizes the amplitude and rate of change of line of sight motion will allow the ABI-GS to output data that meets the system INR requirements sooner after solar eclipse and spacecraft maneuvers and is therefore desirable.

The line of sight motion **shall** be repeatable to within ± TBD μrad from day to day assuming constant solar elevation angle. The peak residual error between the ABI line of sight motion and a fitted function (assuming 8 stars and 20 landmarks per hour and their associated measurement errors) **shall** be less than ± TBD μrad over a 24 hour period. During a solar eclipse, the peak residual error between the ABI line of sight motion and a fitted function (using no more than 4 stars and 10 IR landmarks per hour) **shall** be less than ± TBD μrad over an 8 hour period around the eclipse.

3.2.4.7 Servo Error and Transfer Function

The ABI **shall** ouput a servo error, the difference between the commanded and measured position of the scanning system reported to the ABI-GS (line of sight relative to the gimbal mounting surface). The servo error **shall** be embedded in the sensor raw data stream. During image data collection, the servo error, converted to a line of sight pointing error**, shall** be accurate to ±TBD μrad.

3.2.4.8 Line of Sight Transfer Function

The ABI **shall** be able to determine the transfer function, in all 3 axis, from the instrument mounting feet to line of sight given the spacecraft to instrument disturbances defined in the ABI IRD. The transfer function shall be accurate to ±4 μrad (TBR).

3.2.5 RADIOMETRIC ACCURACY AND PRECISION

3.2.5.1 On Orbit IR Calibration and accuracy

The ABI **shall** have full system and full aperture on-board calibration for the IR channels with wavelengths greater than 3 microns. The ABI **shall** be calibrated to an absolute accuracy of ±1 Kelvin at a 300 K reference temperature, traceable to the NIST radiometric and temperature standards.

3.2.5.2 Relative Precision

For all channels, the ABI **shall** have a pixel to pixel relative precision less than the temporal noise achieved in each channel. For all channels, the ABI should have a pixel to pixel relative precision less than 1/3 the temporal noise achieved in each channel. The pixel to pixel relative precision, also known as the residual spatial noise, is computed after the operational calibration and resampling algorithms have been applied. The value is computed as the RMS error, after temporal averaging, over an image area the size of a channel's focal plane array (FPA) while viewing a stable, uniform calibration source.

For all channels, using an image created by viewing a stable, uniform calibration source for the time period equivalent to covering the full disk, the mean of any 10 by 10 area of pixels **shall** not differ from the mean of any adjacent 10 by 10 area of pixels by more than half the average temporal noise of those pixels. Nominal space reference rate during the full disk coverage time period is allowed.

For channels with wavelengths greater than 3 microns, the ABI **shall** have a RMS relative precision of 0.2 Kelvin, at a 300 K reference temperature, in the following areas: channel to channel, image to image, and IR calibration to IR calibration. The previous three relative precision categories are computed after removing, through averages, the temporal and spatial noise for each channel and detector. For example, the image to image relative precision for a given channel is computed by determining the average value for each of a series of images while viewing a stable calibration source. The RMS relative precision is computed, after removal of the mean, over this series of average images.

3.2.5.3 Coherent Noise

The ABI coherent noise and/or coherent frequencies in all channels **shall** not exceed 0.11% RMS of full scale of the scene dynamic range (table 1) in the raw data. All commercial power line frequencies and their harmonics up to 5 kHz (TBR) are exempted.

3.2.5.4 On orbit Vis/NIR calibration

The ABI should have an on-board calibration capability for the visible and near IR (VNIR, 0.86, 1.3 and 1.6 micrometer) channels that provide: absolute accuracy of 3%, at 100% albedo, or less, RMS repeatability of 0.2% or less, and drift in absolute calibrated radiances of 0.5% over ABI lifetime. The calibration should be NIST traceable.

3.2.5.5 Spatial uniformity of data

The ABI should have less than 0.25% (TBR) change, relative to the scene dynamic range in Table 1, in optical throughput over the field of regard. The ABI **shall** have less than 0.1% (TBR) change in response in the calibrated data over the field of regard while viewing a constant scene.

3.2.5.6 Defective Pixels

The ABI processed data **shall** have no (TBR) defective pixels. A defective pixel is one that is not compliant with any requirement listed in this document.

3.2.5.7 Cross Talk

3.2.5.7.1 Out of Band Cross Talk

The ABI channel to channel (electrical, optical, spatial, spectral,..) crosstalk **shall** be less than one NEDN. This is verified by having all ABI channels except one scan a step response from zero radiance to N_{max} in Tables 1 and 2. The one channel **shall** not have any correlated changes greater than one NEDN.

3.2.5.7.2 In Band Cross Talk

Non-adjacent detector to detector cross talk, not including diffraction, **shall** be less than one NEDN. This is verified by scanning an edge or slit from zero to N_{max} in Tables 1 and 2 over one detector and detecting correlated changes in all other non-adjacent detectors.

3.2.5.8 Blooming

All detectors in channels with center wavelengths less than 4.0 microns **shall** recover to normal operation after an exposure to twice N_{max} (see tables 1 and 2 in paragraph 3.2.2.1 and 3.2.2.2) within 5 (TBR) output pixels.

3.2.5.9 Stray light (TBS)

3.2.5.10 Quantization Step Size

The quantizing step size for all channels **shall** be less than the NEDN in Tables 1 and 2 and <u>should</u> be less than 1/3 of the NEDN.

3.2.5.11 Analog to Digital Converter Differential Linearity

The differential nonlinearity, except for the 0.64 micron channel, **shall** be less than 1/3 of the least significant bit.

3.2.5.12 Electronic In-Flight Calibration

A system for calibrating and/or checking the linearity of the electronics and analogue to digital converters **shall** be incorporated. The calibration signal input non-linearity **shall** be less then 0.1% of full scene, and the amplitude shall be greater than the dynamic range of the channel. The calibration signal **shall** be inserted as close to the detector output signal as practical in the electronics chain.

3.2.6 SYSTEM DYNAMIC RANGE AND LINEARITY

The ABI **shall** have a dynamic range sufficient to measure the minimum and maximum scene brightness listed in Table 1 without saturation over the lifetime of the instrument. The ABI **shall** have linear radiometric response, before calibration, to within 1% over the lifetime of the instrument.

3.2.7 SPACE ENVIRONMENT

The ABI **shall** provide radiation protection by means of local shielding and/or satellite structure, as defined in the ABI IRD, to assure meeting required performance of all parts in the instrument modules for the lifetime (ref 3.2.11) of the instruments. The satellite radiation environment is defined by the GSFC document X-900-97-04.

The ABI **shall** be designed to prevent latchups and minimize the occurrence of single event upsets and unintentional commands due to cosmic ray spectrum. No damage to the instrument **shall** result from any single event upset or unintentional command.

The optical system and surface coatings **shall** be designed to allow the ABI to provide the required performance over the life of the sensor. The coating selected for the scan mirror and optics **shall** have demonstrated (by flight or ground testing) long life performance in the combined solar input plus orbital particle environment.

3.2.8 DATA RATE AND COMPRESSION

3.2.8.1 Data Rate
The ABI data rate to the spacecraft **shall** not exceed 15 (TBR) megabits per seconds (Mbps).

3.2.8.2 Compression of channels with wavelengths > 3 microns
Data compression of these channels, if necessary, **shall** be carried out by any means that permit lossless reconstruction of the data. Lossless compression <u>should</u> use the CCSDS standard algorithms.

3.2.8.3 Compression of channels with wavelengths < 3 microns
Compression of these channels **shall** meet the requirements listed in Table 5 and **shall** pass TBS government sponsored field tests to verify acceptable image quality for NOAA science product generation. The reconstructed data **shall** also meet the system MTF requirements listed in Table 4.

Table 5.
Visible Data Compression Requirements

Metric	Definition	Requirement

Peak SNR	$PSNR = 20\log_{10}\left\{\frac{(2^b - 1)}{RMS(error)}\right\}$ where b is the number of bits, and *error* is the difference between the original and reconstructed image	PSNR >= TBSdB
Correlated noise	$M=0.5*(M_{hGBIM} + M_{vGBIM})$, where M_{hGBIM} and M_{vGBIM} are defined in [1]	$\frac{M_{RC}}{M_{ORIG}} < 1.1$, where M_{RC} is the metric for the reconstructed image, and M_{ORIG} is for the original image

[1] H.R. Wu, "A New Distortion Measure for Video Coding Blocking Artifacts," in Proceedings of the 1996 International Conference on Communication Technology, vol. 2, May 5-7, 1996, Beijing, China, pp. 658-661.

3.2.9 MASS, POWER, VOLUME

Refer to ABI IRD.

3.2.10 COOLING

All detector cooling should be passive. Twice per year, the spacecraft will perform a yaw flip (ref 3.1.4.7.1) of 180° to reduce solar loading on the cooler. Total area available for cooling should be consistent with instrument dimensions in the ABI IRD

3.2.11 LIFETIME

The ABI **shall** have a design life of 10 years of operation after up to 2 years of on orbit storage with reliability at design end-of-life of 0.6. In addition, the ABI **shall** withstand two years of ground storage. The use of redundancy should be maximized.

3.2.12 TELEMETRY

The ABI **shall** measure all instrument components (temperatures, voltages,…) necessary for accurate radiometric calibration and health and safety monitoring. The health and safety information **shall** be in the spacecraft telemetry and all telemetry data must be included in the ABI data stream. The **ABI shall** ingest and include in its output data stream spacecraft attitude and housekeeping information defined in the IRD.

3.2.13 TORQUE MARGINS

All electromechanical subsystems **shall** provide beginning of life force and torque ratios of 4 for all unknown forces or forces varying over the mechanism lifetime and 1.25 for all known forces. Known forces include inertias and well-characterized spring forces while unknown forces include friction and flexure stiffness changes predicted over the mission lifetime. The mechanisms **shall** provide force margin and torque margin by satisfying the following requirement under all worst case operating conditions:

$$Ta = 4*Tu + 1.25*Tk$$

where:

Ta = Torque (or force) available
Tu = Estimated peak torque (or force) from uncharacterized or unpredictable (unknown) sources
Tk = Peak torque (or force) from well-known sources

3.2.14 STABILITY MARGINS

All closed loop control systems **shall** provide stability margins of:

Gain margin > 6dB
Phase Margin > 40 degrees

3.2.15 PROCESSING MARGIN

All ABI flight computers **shall** have 100% margin in computation load and memory capacity.

APPENDIX A: ACRONYMS AND ABBREVIATIONS

ABI	Advanced Baseline Imager
ABI-GS	ABI-Ground System
A/D	Analog-to-Digital
AOS	Advanced Orbiting Systems
BOL	Beginning of Life
CCSDS	Consultative Committee on Space Data Systems
CDA	Command and Data Acquisition
CONUS	Continental United States
Cyc	Cycle
DMC	Dynamic Motion Compensation
EOL	End of Life
FOR	Field-of-Regard

FPA	Focal Plane Array
GOES	Geostationary Operational Environmental Satellite
IFOV	Instantaneous Field of View
INR	Image Navigation and Registration
IR	Infrared
IRD	Interface Requirements Document
ISO	International Standards Organization
K	Kelvin
Km	Kilometers
LOS	Line of Sight
M	Meters
Mbps	Mega-bits-per-second
MTF	Modulation Transfer Function
MW	Milli-watt
NASA	National Aeronautics and Space Administration
NEDN	Noise Equivalent Delta Radiance
NEDT	Noise Equivalent Delta Temperature
NESDIS	National Environmental Satellite, Data, and Information Service
NIR	Near Infrared
NIST	National Institute of Standards and Technology
Nmax	Maximum Scene Radiance
NOAA	National Oceanic and Atmospheric Administration
O&A	Orbit and Attitude
ORD	Operational Requirements Document
PSNR	Peak Signal-to-Noise Ratio
RFP	Request for Proposal
RMS	Root Mean Square
SMC	Spacecraft motion compensation
SOCC	Satellite Operations Control Center
SOIF	Spacecraft Onboard Interface
SNR	Signal-to-Noise Ratio
SOW	Statement of Work
Sr	Steradian
TBD	To be determined
TBR	To be reviewed
TBS	To be supplied
Tmin	Minimum Scene Temperature
Tmax	Maximum Scene Temperature
TRD	Technical Requirements Document
μm	Micrometers (Microns)
μrad	Microradian
Vis	Visible
VNIR	Visible/Near Infrared